How to maximize the value of mature HC fields?

Evaluation of CCS possibilities in Hungary

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Society of Petroleum Engineers

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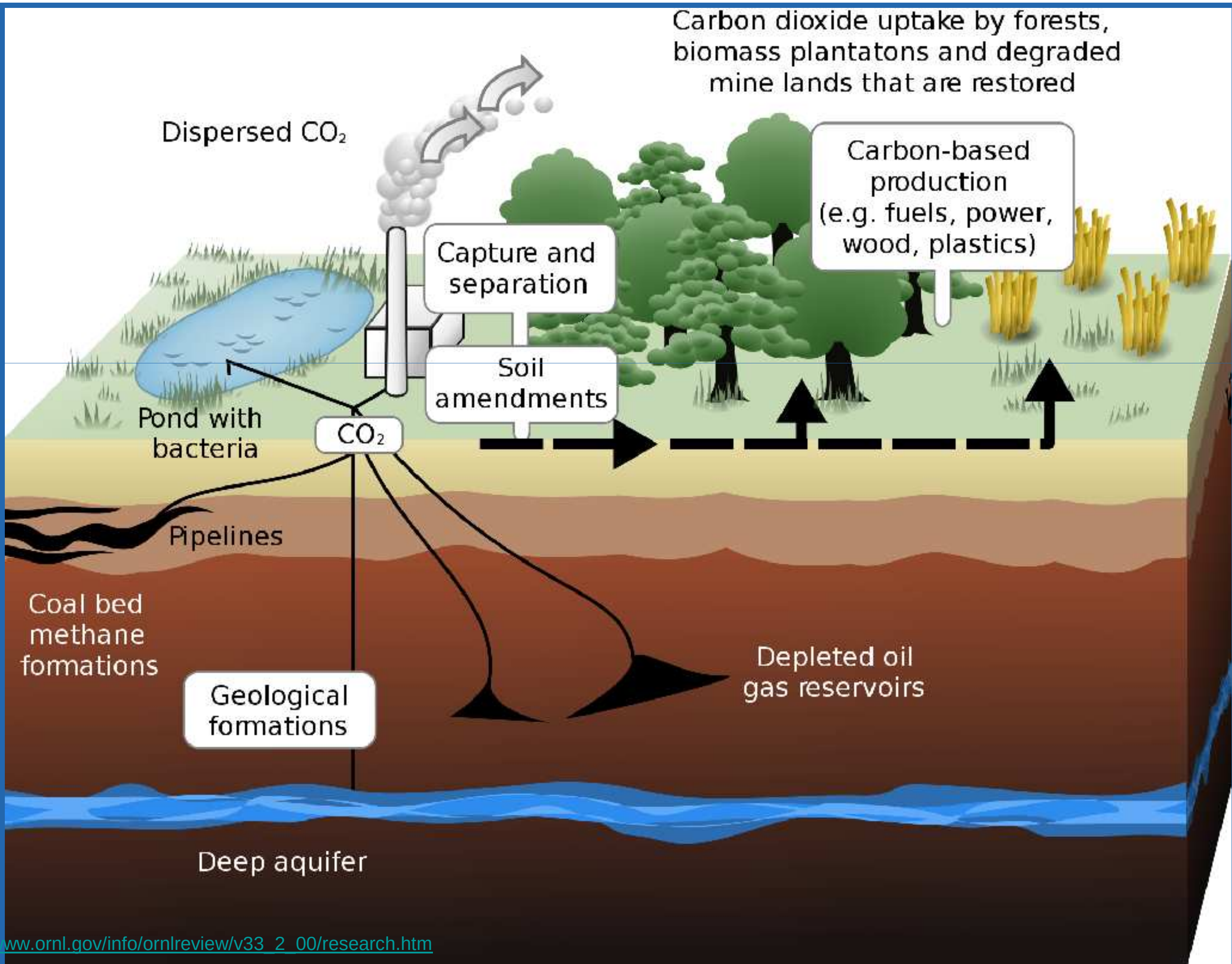
- **Geological storage of CO2**
- **Case study in Hungary: Mátra CCS**
- Risks of storing CO2, Risk-management
- **Reservoir engineering study**

CCS Carbon Capture and Sequestration



Source: http://www.ornl.gov/info/ornlreview/v33_2_00/research.htm

CO_2 storage possibility in Hungary

The available alternatives for storing CO_2 :

- **depleted oil and gas fields**
- **deep saline aquifers,**
- **unmineable coal beds**

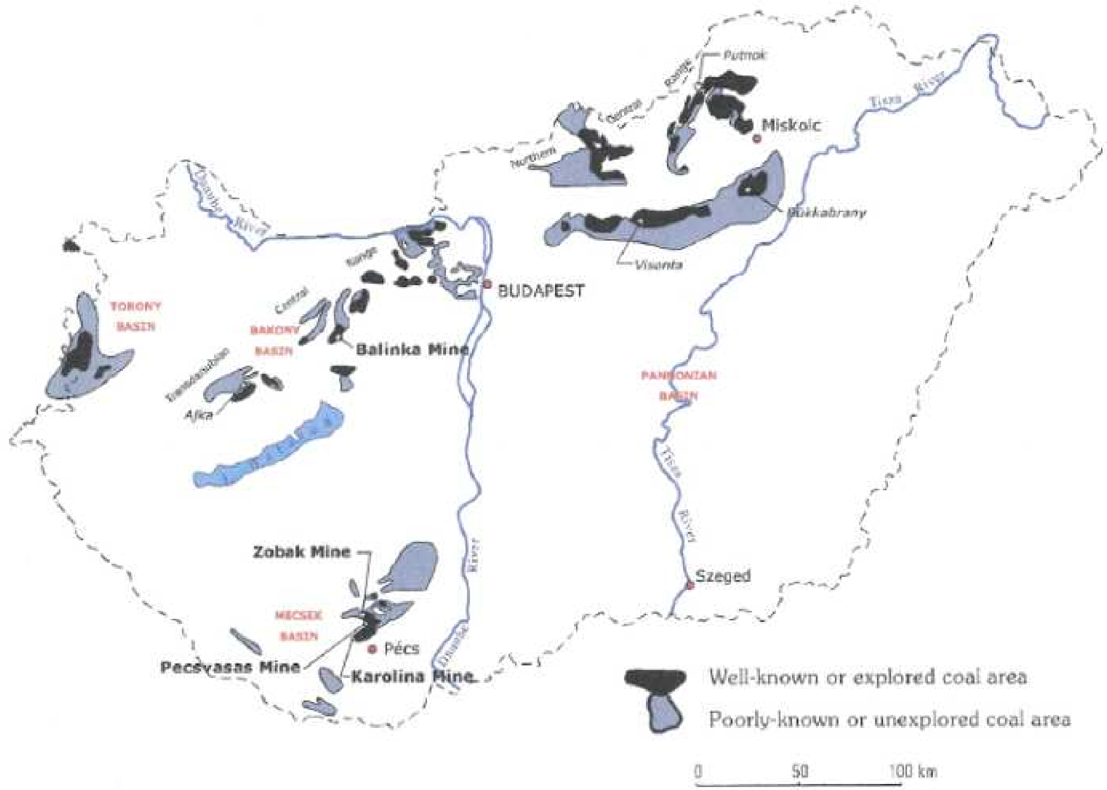
In 2009 our R&D study presented answers in

- **CO_2 storage possibilities** in Hungary
  - in deep saline aquifers
  - coal beds
- **CO_2 storage potential** of the **depleted hydrocarbon reservoirs** in Hungary

Storing in unmineable coal seams

CO_2 gas can be adsorbed on the surface of the coal and in the fractures

Estimation of the storage capacity : 300 Million t CO_2.



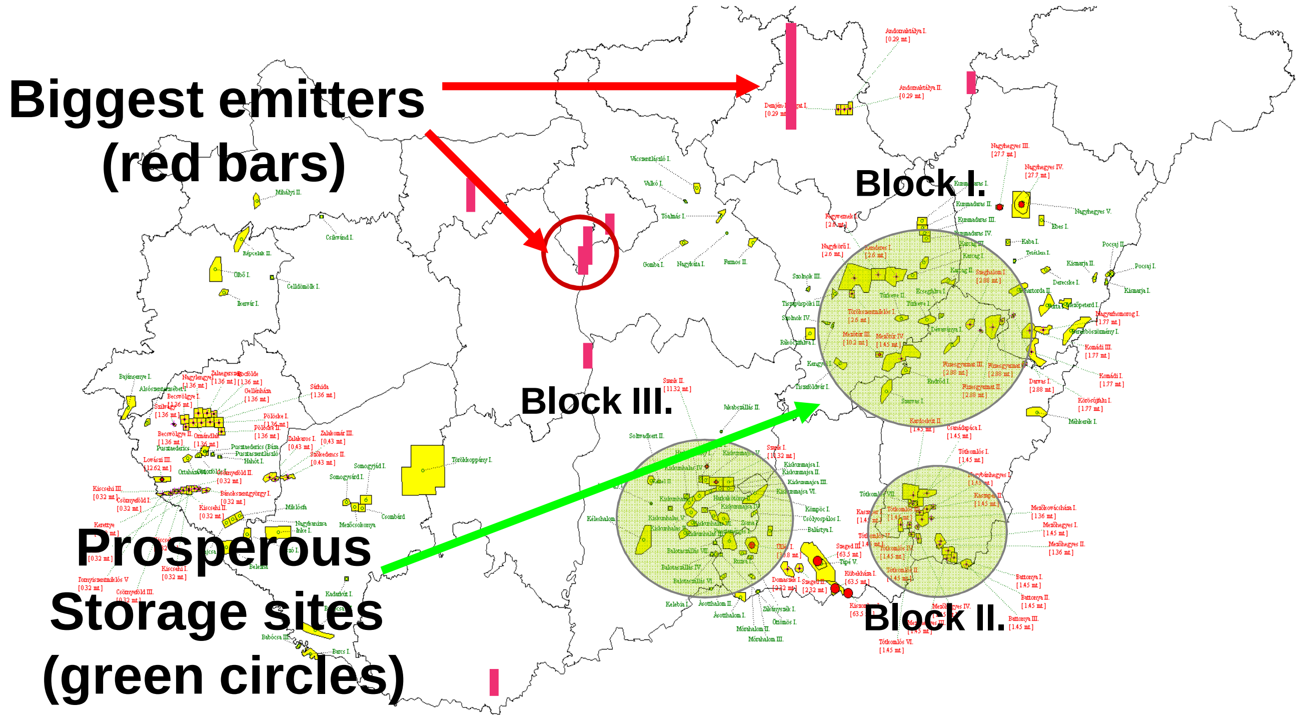
The efficiency of the adsorption of the Hungarian coals is very low, so this storing method is not relevant.

Storing in depleted oil and gas fields

Reservoirs were excluded if:

- capacity less than 1 million tons.
- operated as an underground gas storage
- surface is highly populated
- bad geology or well conditions

Hungarian R&D study: 180 oil or gas reserves were investigated for volumetric calculation

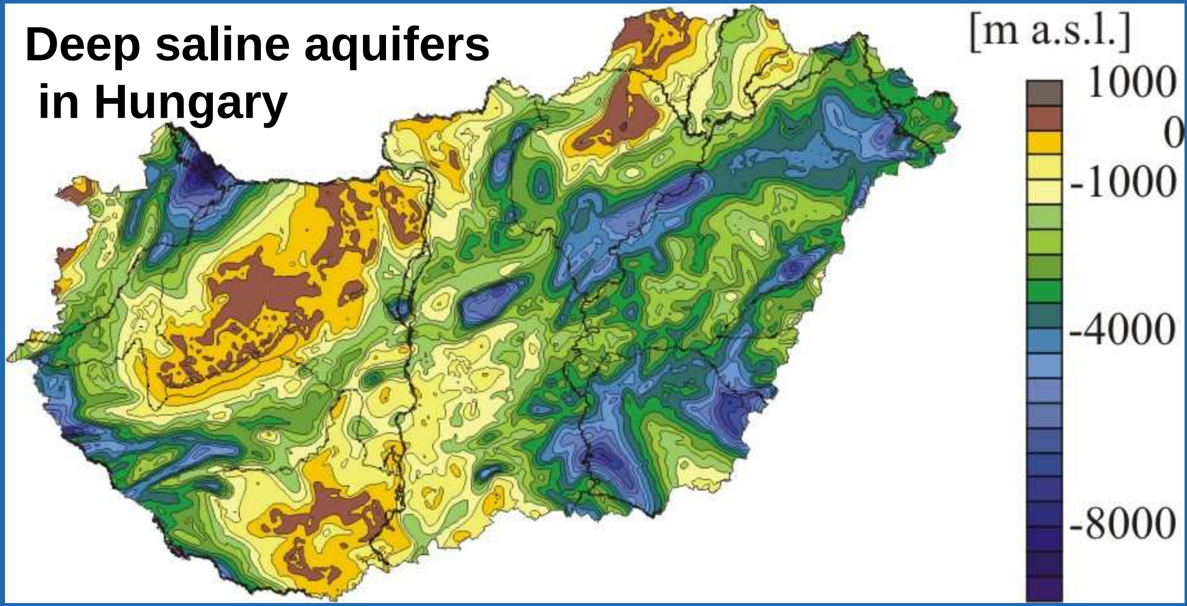


23-26 reservoirs are technically and economically **viable for CO_2 storage** with **max. 150 Million tons of CO_2 capacity**

Storing in deep saline aquifers

Suitable aquifers are at least 800 meters depth and contain water not drinkable.

The exact **location** and the real volume of the saline aquifers are **partly known**



Huge **exploration cost** needed for creating reservoir engineering studies by carrying out **3D seismic surveys, and exploration drills**

Storing in aquifer - Szolnok Formation

Criterion:

- proven regional seal
- more than 800m depth
- sufficient CO_2 storage capacity
- Effective petrophysic properties

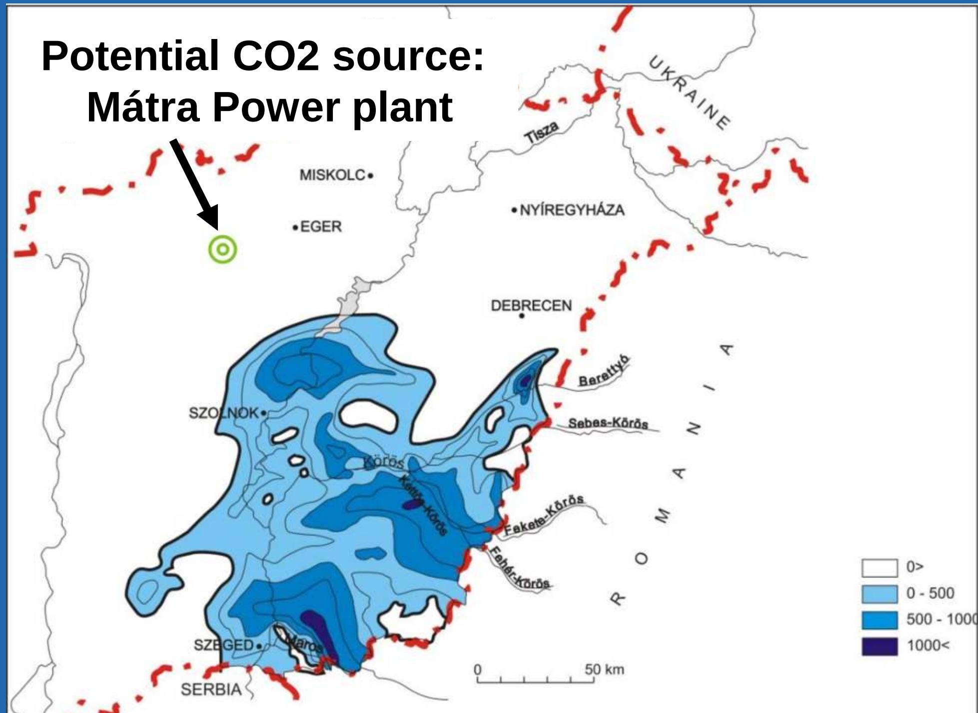
Estimation of the storage potential

Storable CO_2 quantity (by Prof. Pápay, 2007):

$$M_{CO2}=\varphi_x c_x V_x \Delta p_x \rho_{CO2}$$

where:

M_{CO2} – storable CO_2 mass in the aquifer (kg)
φ - aquifer porosity
c - effective compressibility (1/bar)
(rock and the water in the rock pores)
Δp - over-pressure; value: Δp0.2pi (bar)
V - aquifer rock volume (m3)
ρ_{CO2} - CO_2 insitu density (at actual p, T) (kg/m3)



Thickness map of the Szolnok Formation

Theoretical maximum amount of 2510 Million t CO_2

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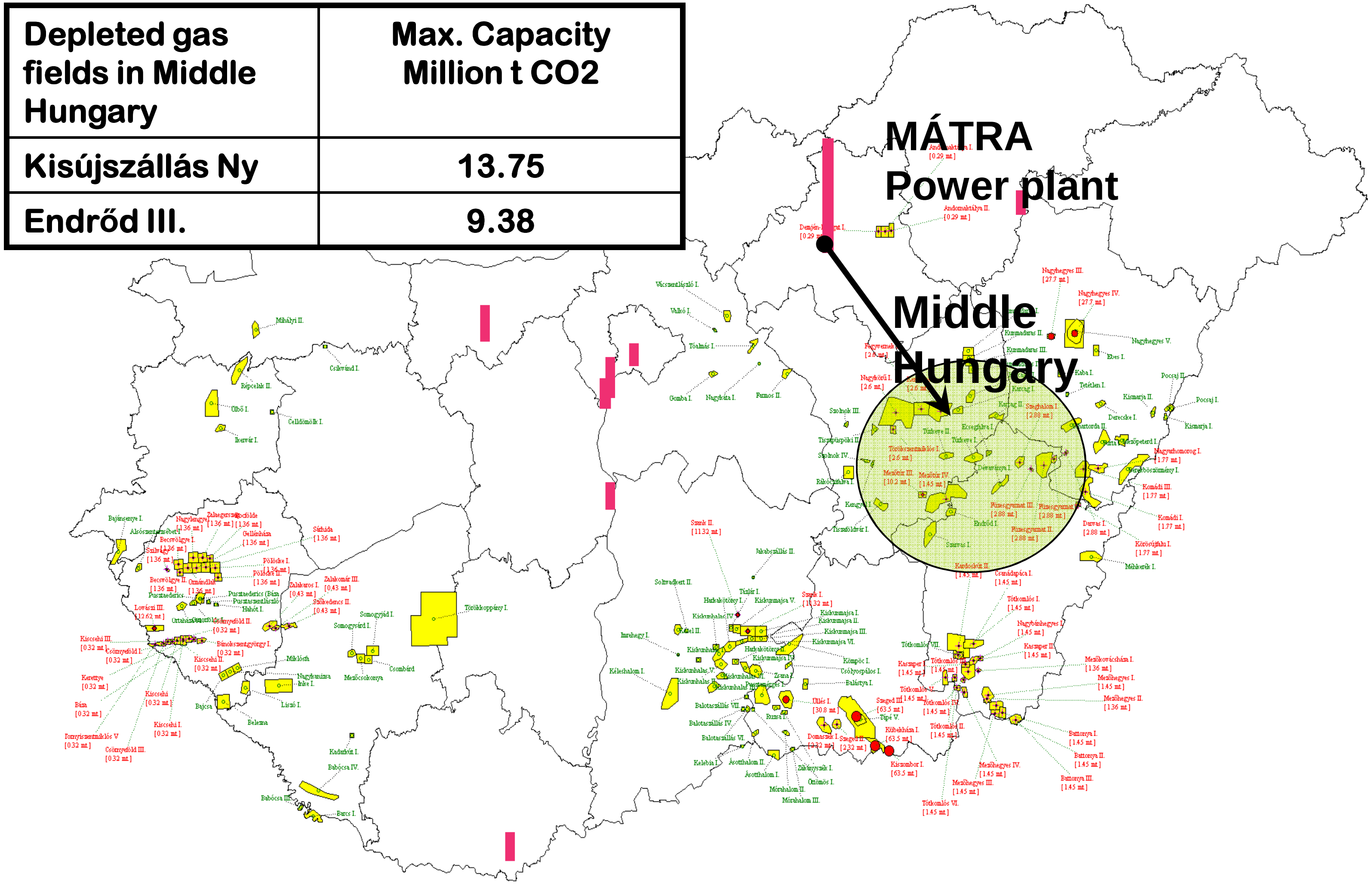
Possible Capture and Storage sites in Hungary

Depleted gas fields in Middle Hungary	Max. Capacity Million t CO_2
Kisújszállás Ny	13.75
Endrőd III.	9.38



Data of Capture in Mátra CCS Project

Capture area

POWER GENERATION
The new lignite-fired power plant unit
Capacity: 500 MW
Net efficiency: ≥ 42% (elec.)

Post combustion based on chemical absorption (amine) in combination with heat induced CO_2 recovery.

CAPTURE

Technology:	**post combustion**
CO_2 absorber:	**MEA**
Capture efficiency:	min. 85%
Efficiency with CCS:	**32-33%**
Outlet CO_2 pressure:	100 bar
Status:	feasibility study

Data of Transport and Storage in Mátra CCS

STORAGE

First storage phase: in depleted gas fields

well known

Second storage phase in the regional aquifer

More data are needed

TRANSPORT

CO_2 transportation via pipeline

Formation: Depleted hydrocarbon (gas) reservoirs

- field Kisújszállás Ny.
- field Endrőd III.

CO_2 capacity:	**ca. 24 Million t**
Fill-up time:	7 years
Depth:	1200-2000 m
Reservoir rock:	sandstone

Formation: Aquifer (Szolnok Fm), (close to Endrőd)

Depth of top:	> 800 m
Porosity:	15-25%
Permeability:	40-80 mD
Thickness:	800-1000 m
Storage capacity:	**ca. 250 Million t**

From the Power Plant to the Storage site

Length:	116 km
Diameter:	350 mm
Pressure:	120 bar

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Risks of storing CO_2

<u>Leakage</u> is the most significant risk of CO_2 storage:

Risks:

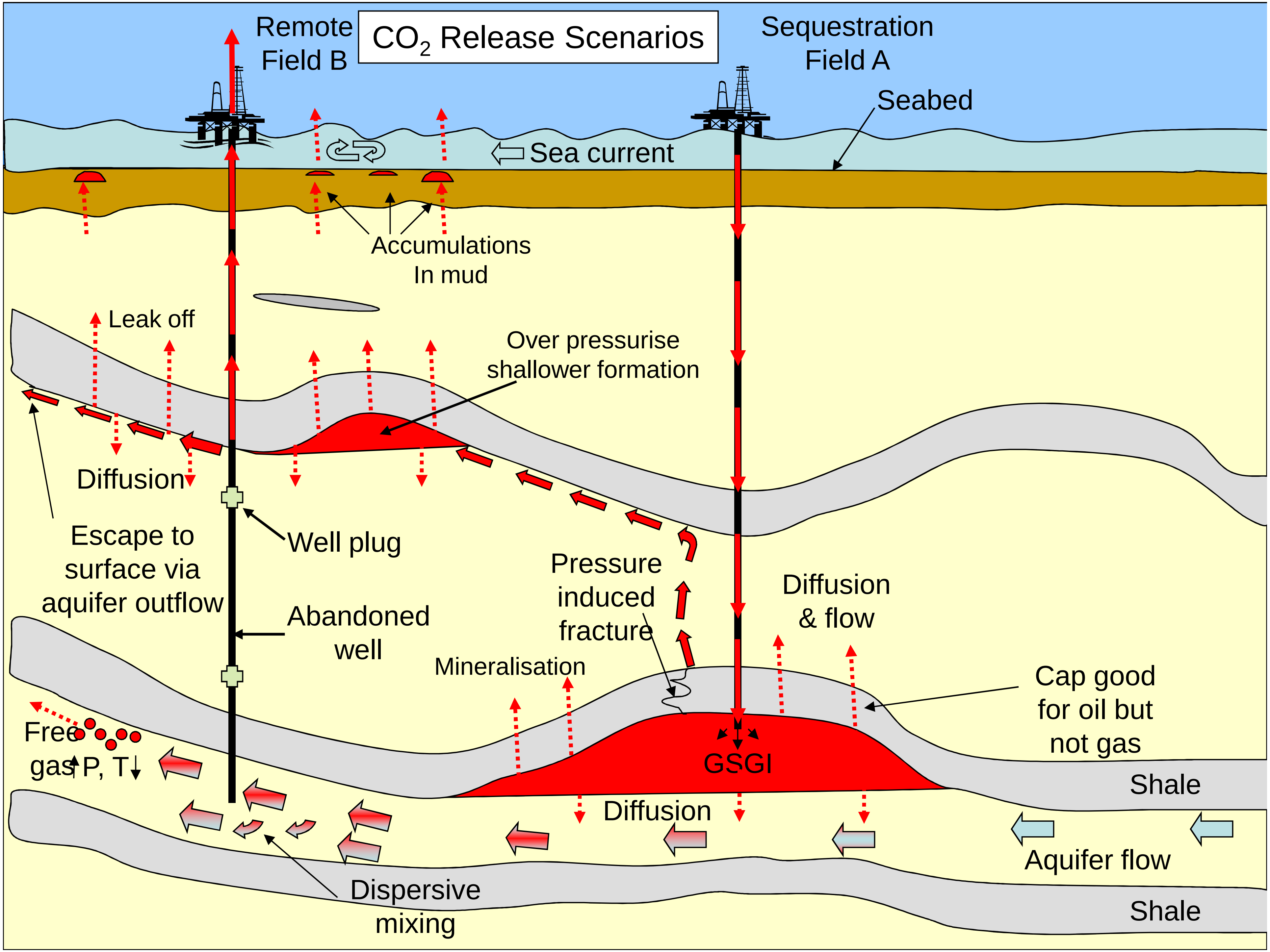
CO_2 leakage from the reservoir to the upper layers and to atmosphere

Reactivation of fractures

Ground movement

Displacement of brine

- CO_2 leakage can occur in case of the inability of the cap rock
- CO_2 can escape through the old wells if they are not plugged in the proper way
- through aquifer flows in the reservoir.



CO_2 Release Scenarios
Remote Field B
Sequestration Field A
Seabed
Sea current
Accumulations In mud
Leak off
Over pressurise shallower formation
Diffusion
Escape to surface via aquifer outflow
Well plug
Abandoned well
Pressure induced fracture
Diffusion & flow
Mineralisation
Cap good for oil but not gas
Free gas ↑P, T↓
GSGI
Diffusion
Shale
Aquifer flow
Dispersive mixing
Shale

Risk management of CO_2 storage:
1. Site selection

Good reservoir parameters go half the way towards mitigating risks

Good storage parameters

- **High porosity**
- **Big storage volume**
- **High permeability**
- **Low temperature**
- **Appropriate cap rock with good sealing**
- **Geologic and Hydrodynamic Stability**

Preparation of site selection in deep saline aquifers:

1. Re-evaluation of old 2D seismics
2. Re-evaluation of drilling data of old wells
3. Making pre-estimated geology maps with cap rocks
4. Evaluate candidate areas
5. Determine the best candidate
6. Execute 3D surveys
7. Evaluate 3D surveys
8. Exploration wells drilling with mugs
9. Geology study and Evaluation

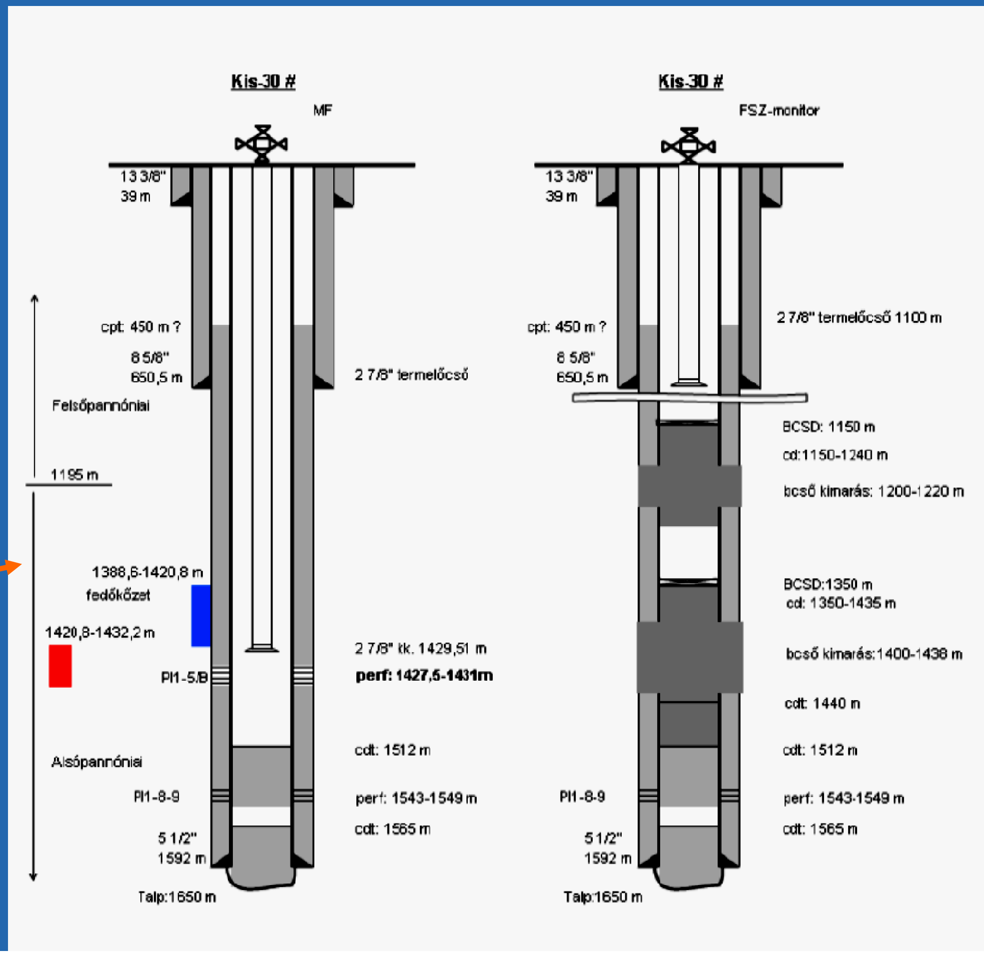
Risk management of CO_2 storage: 2. perfect well conditions

Old wells can be used for injection or monitoring if only they have:

- CO_2 resistant cement,
- perfect cement measurement
- good casing

Most of the wells do not have CO_2 resistant cement and casing, it is a must to drill new wells for the purpose of injection

Avoiding the leakage problems we have to abandon most of the existing wells.



Risk management of CO2 storage: 2. perfect well conditions

<u>Vertical wells</u> in hydrostatic pressure aquifer <u>are not suggested</u>:

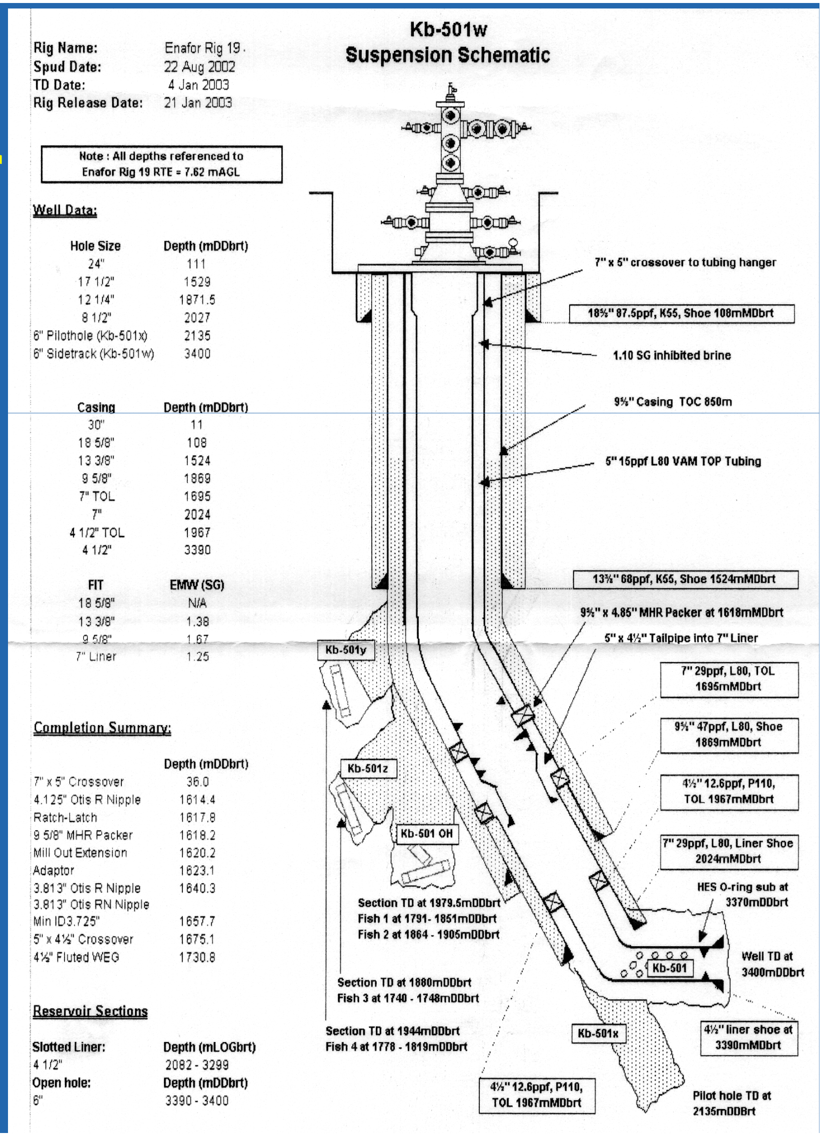
- **in the long vertical section the suppression can cause fractures at the top!!!**

In Salah CO2 injection:

<u>1,4 Mm3/day</u> into a low permeability sandstone by <u>3 horizontal wells</u>

Formation thickness: 20 m
Permeability: 10-20mD
Pressure: 185 bar

<u>Horizontal segment</u>: <u>1200 m long</u>



Risk management of CO_2 storage: 3. Monitoring

Examples of monitoring techniques

The stored CO_2 quantity and the trapping mechanism have to be verified,

and this system can provide early warning of storage failure.

Monitoring group	***Monitoring technologies***	***Compartment***
Engineering	**Pressure, temperature**, well tests	Wells
Geophysical	**Seismics (3D),** micro seismicity, gravimetry, electro-magnetic, self-potential, physical well logging	Reservoir and back -ground system, wells
Geochemical	Production **water & gas analysis**, **tracers**, overburden fluids, direct measurements	Reservoir and surface system
Geodetic	Geodetic, tilt measurements, **satellite interferometry**, airborne sensing	Surface system, space
Biological	Microbial, **vegetation changes**	Surface and background system

Monitoring CO2 in In Salah

- The project has several key features which make it unique among the early mover CCS de…
desert location, with storage in low-permeability rock formations in the saline aquifer adjace…
- This demonstration project is relevant to many future CCS sites in in continental locations…

Monitoring/Modeling Studies/Reviews: 2005-2009

Monitoring technology	Risk to monitor	Action
Wellhead sampling	Wellbore integrity Plume migration	- 2 monthly sampling since 2005
Tracers	Plume Migration	- Implemented 2006
Wireline Logging	Subsurface characterization	- Overburden samples and logs collected in new development wells
Soil Gas flux	Surface seepage	- Pre-injection surveys in 2004 - Repeat survey in 2009
3D/4D seismic	Plume migration	- Initial survey in 1997 - High resolution repeat 3D survey in 2009.
Deep observation wells	Plume migration	- Not planned at present due to cost
Microseismic	Caprock integrity	- Pilot well drilled in 2009 above KB-502 - Depth 500m (1500m injection zone) - 50 geophones array (10 three component)
Electromagnetic	Plume migration	- Shown not to be useful at Krechba
Gravity	Plume Migration	-Modelling suggests close to detection limits - May be tested in 2011
VSP	Caprock integrity Fracture evaluation	- Modelling results inconclusive - Decision depending on 3D VSP using microseismic array
Shallow aquifer wells	Contamination of potable aquifer Caprock breach	- Seven shallow aquifer wells drilled - Sampling twice per year
Microbiology	Surface seepage	- First samples collected in 2009/2010
Eddy covariance flux towers and LIDARs	Surface seepage	- Reviewed but ruled out due to weather conditions and potential theft issues - Potential deployment in 2011
InSAR monitoring	Plume migration Caprock integrity Pressure Development	- Used extensively; contributions and commissioned work from several providers - Images captured every 28 days
Tiltmeters/GPS	Plume Migration Caprock Integrity Pressure Development	- To calibrate InSAR deformation - 70 tiltmeters deployed around KB-501

Fit-for-purpose Monitoring

The key question the project had to address was which monitoring methods would be fit-for-purpose at this site. The criteria for determining this include: (a) ability of the method to detect CO2 migration as a fluid or gaseous phase, (b) the practical constraints for surface and down-hole tool deployment, and (c) cost. After a thorough and progressive review of the potential methods, the following monitoring portfolio has emerged:

- Downhole gas analysis (as a baseline for subsurface gas distributions)
- Surface gas analysis (as a baseline for surface gas distributions)
- Production and injection wellhead monitoring (including pressures, temperatures, gas composition, and detection of injected tracers)
- Micro-seismic monitoring (deployed in a dedicated monitoring well)
- Time-lapse 3D seismic (over a limited area of interest)
- Satellite (InSAR) data to detect surface deformation
- Tiltmeters and GPS stations to calibrate surface deformations
- Groundwater wells (to measure base-line groundwater chemistry and flow and to deploy longer-term CO2 monitoring devices)
- Core and well log data to characterise the reservoir and calibrate subsurface models.

Wellhead Monitoring

Seismic and Aquifer Monitoring

Monitoring CO2 by InSAR

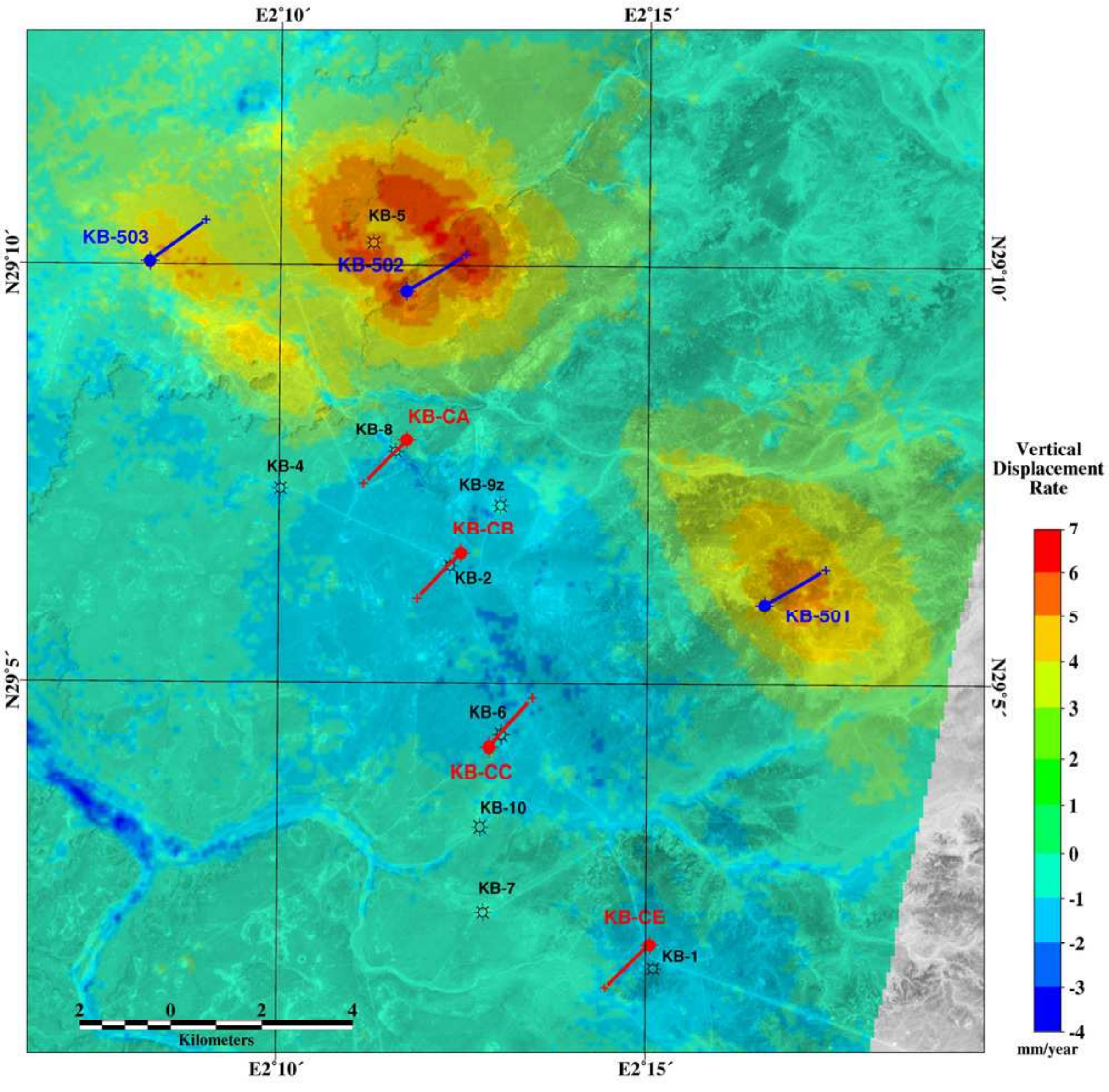
Most interesting
Novel tool:

Satelit Imaging

InSAR:

Changing of 2 mm surface displacement can be measured

4D seizmiks
&
InSAR
show the same picture



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Geological structures and requirements for CCS

CCS can be developed in:

- depleted dry gas fields,
- depleted condensate field,
- depleted oil fields,
- aquifers,
- salt caverns,
- coal beds.

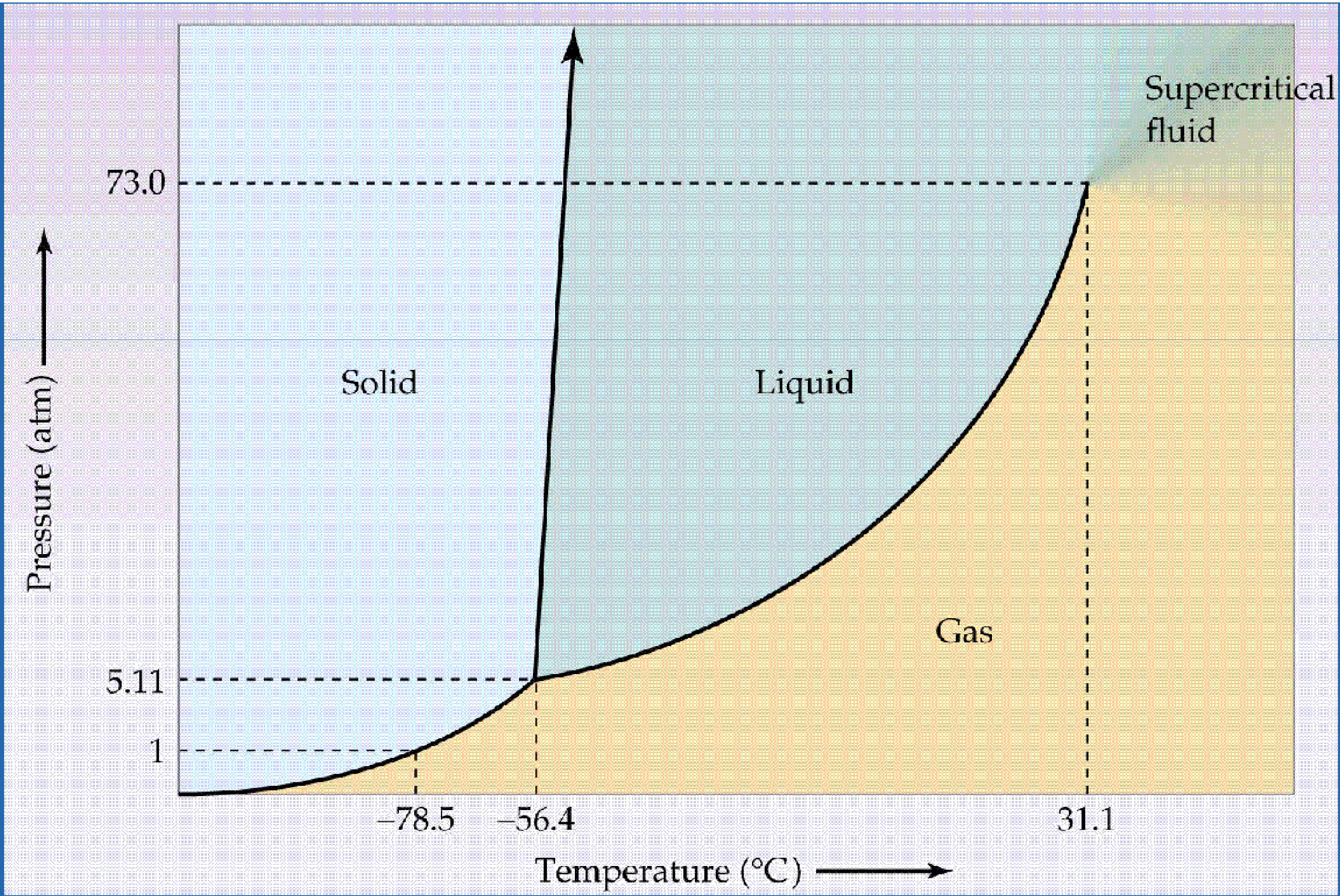
The minimum requierments:

- closure of structure,
- porosity for storage,
- permeability,
- sufficient HCPV in place for CCS,
- caprock integrity against migration and leak,
- sufficient depth (CO_2 fluid or supercritical phase).

Workflow

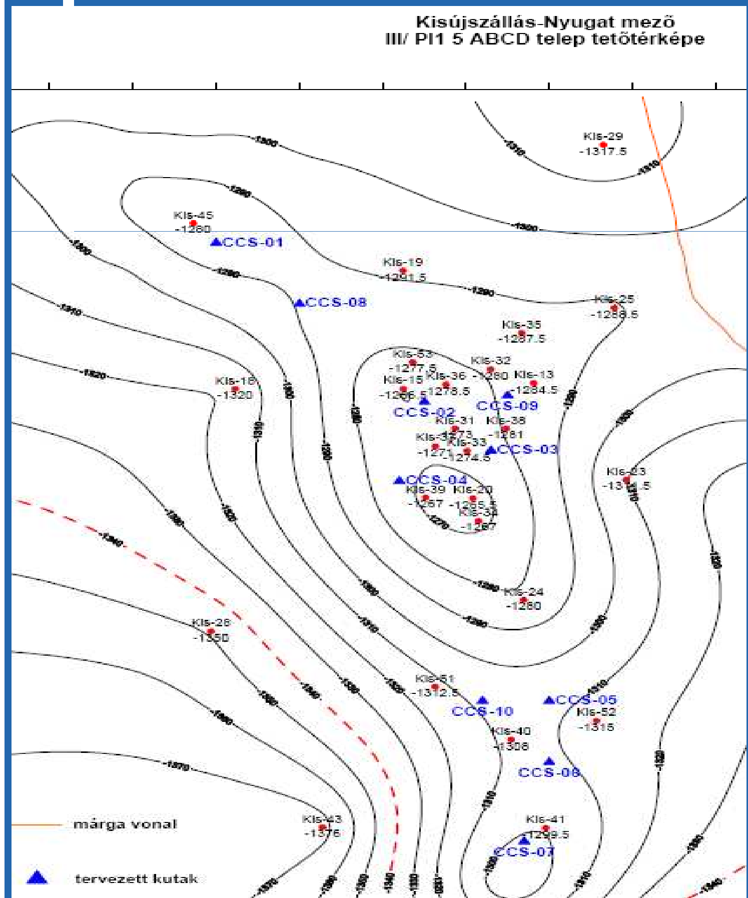
- PVT characterization,
- History matching,
- Well hydraulic modeling,
- Injector well modeling (based on the existing well),
- Define the maximum drawdown (fracture gradient),
- Calculate the optimal injection capacities,
- Calculate the optimal well number,
- Plan existing well abandonments,
- Plan completion of the new injector wells,
- Plan the monitoring system.

CO2 phase behavior



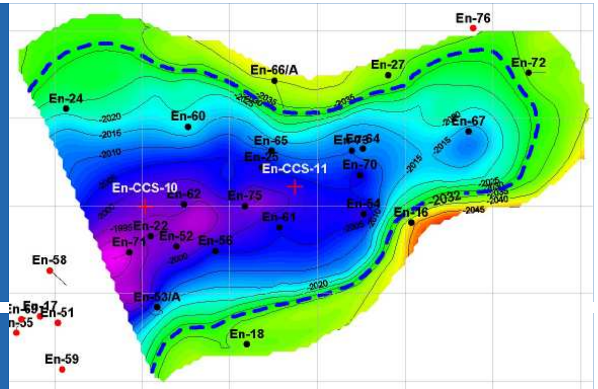
Kisújszállás-Nyugat field

- Only 2 of 19 pannonian reservoir suitable for CCS
- The production started at 1983.



	III/Pl$_1$-5ABCD
GIIP [10^6 m^3]	5260
Driving mechanism	Small water
p_i [bar]	142,5
$p_{05/31/2009}$ [bar]	56-63
$Gp_{05/31/2009}$ [10^6 m^3]	3816,5
Recovery factor [%]	72,6
Producing wells	15
Recoverable gas from 05/31/2009 [10^6 m^3]	187,6
Average injecton rate [10^3 sm^3/well/day]	206

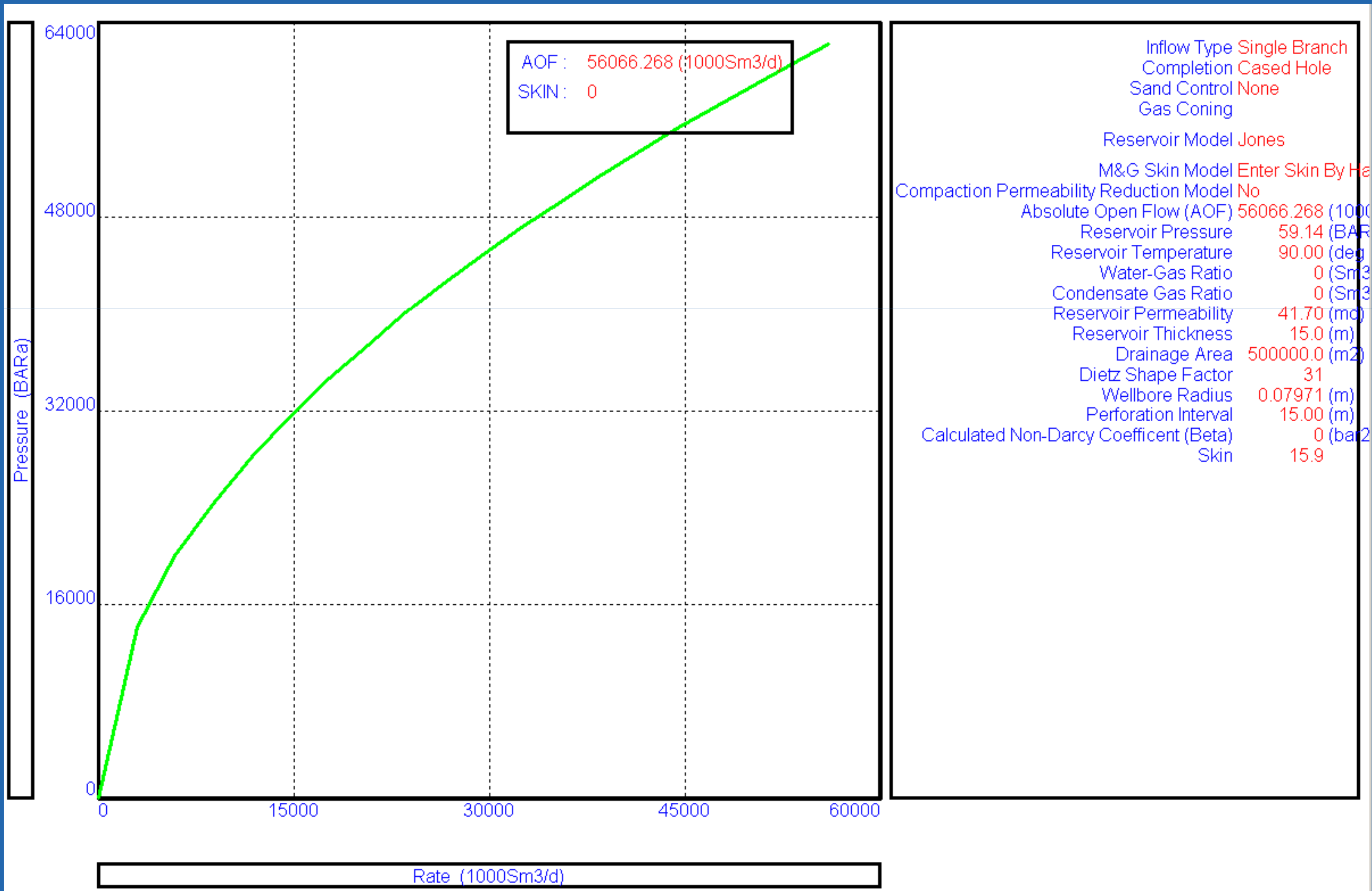
Endrőd-III field



- Only 4 of 29 pannonian reservoir suitable for CCS
- The production started at 1984.

	Pl_1-3/1-K	Pl_1-3/2	Pl_1-3/3-II-K	Pl_1-5/1
GIIP [10^6 m^3]	343,2	520,7	1400	570
Driving mechanism	small water	small water	small water	middle water
p_i [bar]	205	208,5	210,7	216,4
$P_{12/31/2009}$ [bar]	62,5	38	41-47	85
$Gp_{12/31/2009}$ [10^6 m^3]	276	446,9	1211,6	360,3
Recovery factor [%]	80,4	85,8	86,5	63,2
Producing wells	1	1	2	0
Recoverable gas from 2010 [10^6 m^3]	8,1	14,5	40,4	1
Average injecton rate[10^3 sm^3/well/day]	91	160	64,5	91

New injector wells
Inflow Performance Relationships



New injector wells – injection capacities
Fracturing pressure

The fracturing pressure gradient is as follows:

$$\frac{P}{z} = \frac{1}{3z}\left(S_z + 2p\right) \qquad P = \Delta p + p$$

z = depth

P = injection pressure needed to creat a fracture

p = reservoir pressure

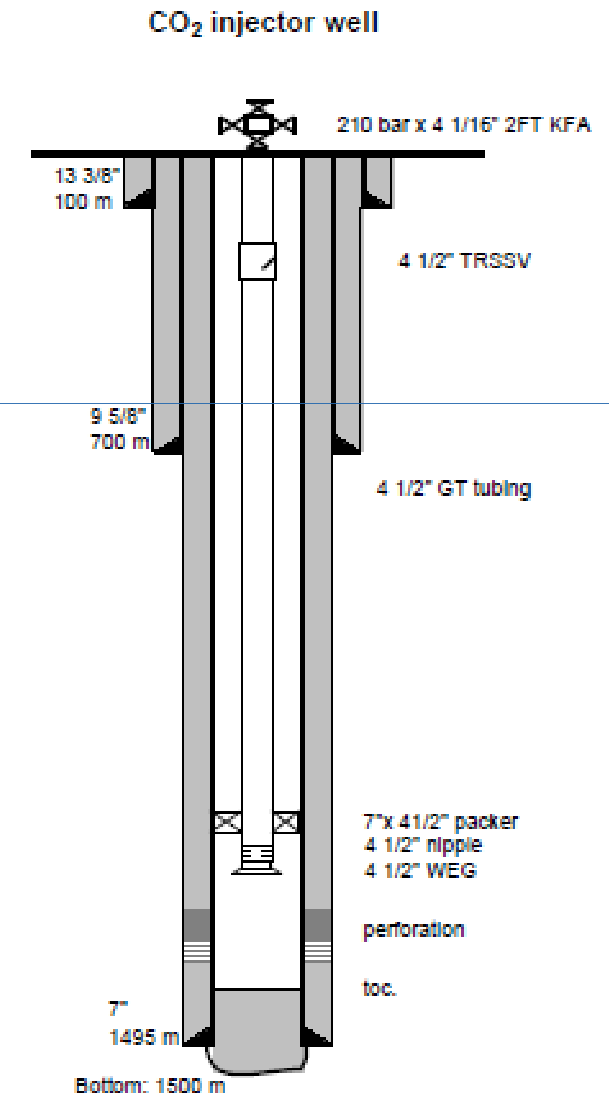
S_z= vertical overburden pressure

$$\frac{P}{z} = 1,4$$

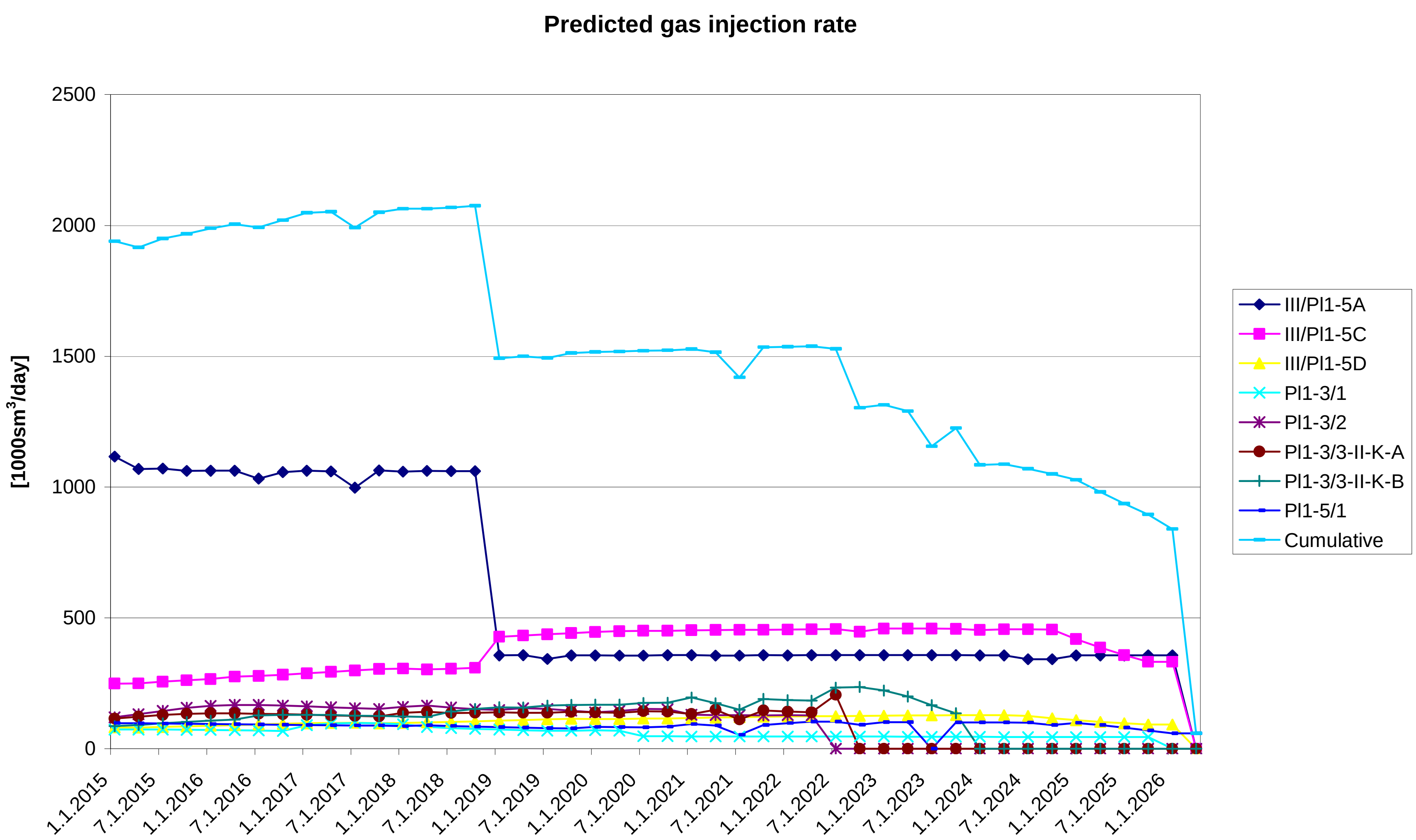
The maximum drawdown can be 40 bar,
near the initial pressure 110 %.

New injector wells in our study

	Kisújszállás-Nyugat	Endrőd-III.
Well number	7-10	7-13
Tubing	4 ½″	2 7/8″
Casing	7″	7″
Bottom [m]	1500	2100

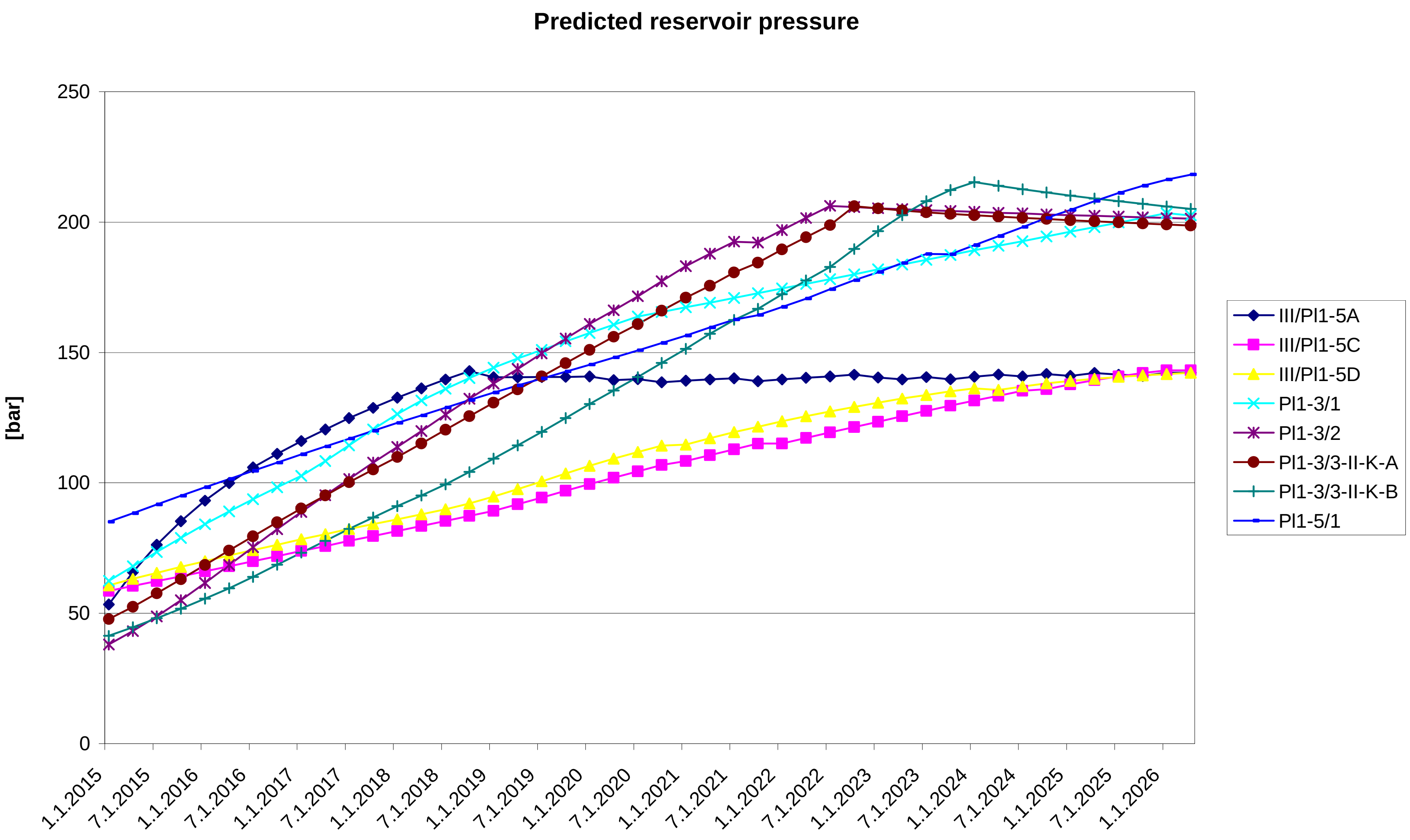


Results



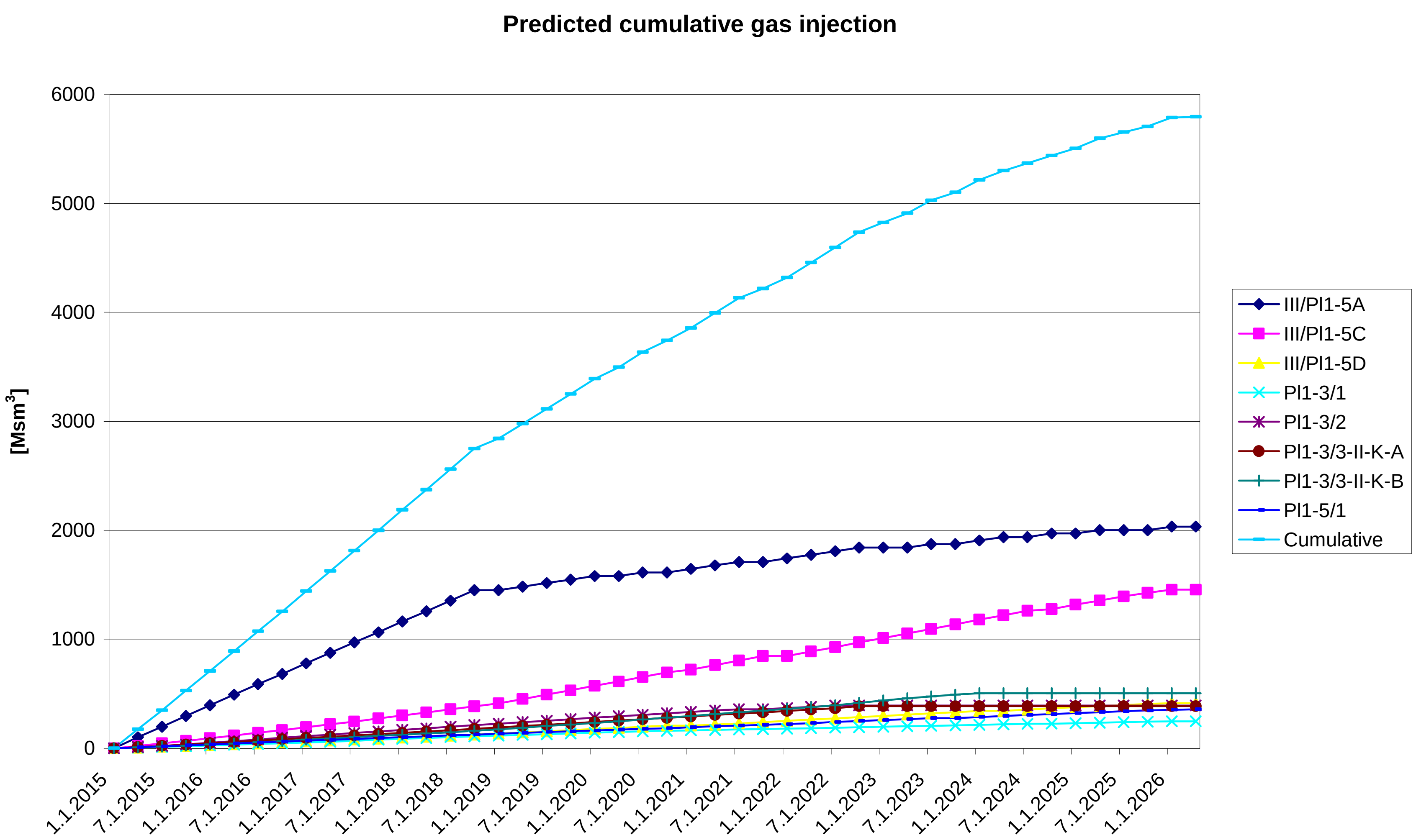
Predicted gas injection rate
2500
2000
1500
1000
500
0
[1000sm3/day]
1.1.2015
7.1.2015
1.1.2016
7.1.2016
1.1.2017
7.1.2017
1.1.2018
7.1.2018
1.1.2019
7.1.2019
1.1.2020
7.1.2020
1.1.2021
7.1.2021
1.1.2022
7.1.2022
1.1.2023
7.1.2023
1.1.2024
7.1.2024
1.1.2025
7.1.2025
1.1.2026
III/Pl1-5A
III/Pl1-5C
III/Pl1-5D
Pl1-3/1
Pl1-3/2
Pl1-3/3-II-K-A
Pl1-3/3-II-K-B
Pl1-5/1
Cumulative

Results



Predicted reservoir pressure
[bar]
250
200
150
100
50
0
1.1.2015
7.1.2015
1.1.2016
7.1.2016
1.1.2017
7.1.2017
1.1.2018
7.1.2018
1.1.2019
7.1.2019
1.1.2020
7.1.2020
1.1.2021
7.1.2021
1.1.2022
7.1.2022
1.1.2023
7.1.2023
1.1.2024
7.1.2024
1.1.2025
7.1.2025
1.1.2026
III/Pl1-5A
III/Pl1-5C
III/Pl1-5D
Pl1-3/1
Pl1-3/2
Pl1-3/3-II-K-A
Pl1-3/3-II-K-B
Pl1-5/1

Results



Predicted cumulative gas injection
[Msm3]
6000
5000
4000
3000
2000
1000
0
1.1.2015
7.1.2015
1.1.2016
7.1.2016
1.1.2017
7.1.2017
1.1.2018
7.1.2018
1.1.2019
7.1.2019
1.1.2020
7.1.2020
1.1.2021
7.1.2021
1.1.2022
7.1.2022
1.1.2023
7.1.2023
1.1.2024
7.1.2024
1.1.2025
7.1.2025
1.1.2026
III/Pl1-5A
III/Pl1-5C
III/Pl1-5D
Pl1-3/1
Pl1-3/2
Pl1-3/3-II-K-A
Pl1-3/3-II-K-B
Pl1-5/1
Cumulative

Summary of our study

	Maximum Injection Rate	Injection well	Monitoring well	Injection time	Well head pressure
	Km^3/day	pcs.	pcs.	year	[bar]
Kisújszállás-Ny	1500	9	4	9	85
Endrőd-III	600	7	5	11	80
Cumulative	2100	16	9		

Storage Potential

Less than → 1 Million t/year capture capacity → Depleted HC fields & aquifers

More than → 1 Million t/year capture capacity → Saline aquifers only

Explorations (3D, drillings, mugs) are needed for knowledge of aquifers

Economics

Economics

in case of 2.5 Million t/year, inland cc. 100 km

Specific costs of Transportation & Storage: **25-29 EUR/ tCO_2**

In case of transportation a storage
relating to an NPV= 0 project
the income of 1 ton CO_2 should be cc. 40 EUR !!!


Thanks for your kind attention!